

**Institute for Computer Science and Control
Hungarian Academy of Sciences**

H-1111 Budapest, Kende u. 13-17, 1518 Budapest, Pf. 63.

Tel: 279-6159, Fax: 466-7503

<http://www.sztaki.hu/>, e-mail: laszlo.monostori@sztaki.mta.hu

**Annual Report 2018
on the Scientific Activity
at MTA SZTAKI**

Budapest, 31 January, 2019

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I. Priorities and main tasks in 2018

The main direction of the Institute's current activity is research in *cyber-physical systems (CPS)* that creates the framework of, and brings the activities pursued here, into the dominant mainstream of international research. Its laboratories (such as the i4D intelligent space, the systems and control, the SmartFactory, the cloud computing and the cooperative cyber-physical research laboratories) were created in line with this end and as a result, new interactions between the theory and the practical engineering approach are being born here.

Expectations towards the cyber-physical systems are already enormous and are growing speedily, simultaneously with the appearance of the new technologies, these being such as robustness, self-organisation, adaptive situational awareness, transparency, predictability, efficiency, inter-operability, and global traceability, to mention only the most important fields. Indeed, notable advances made in areas such as cooperative control, multi-agent systems, complex adaptive systems, emergent systems, sensor networks, data mining and so on, have been reinforcing the expectations of further significant progress, thus strengthening the demand for continuous research.

Their mission statement defined in 2016 says: "relying on its strong – and characteristically focused – basic research activities, MTA SZTAKI generates new results while utilising a framework of widespread domestic and international cooperation, and facilitates their applications to the benefit of the sustainable development of the economy and society, and, at the same time, avails in its fields of activity to preserve and, as far as possible, to raise the Hungarian scientific-technical culture to a higher level."

The goals for 2018 were defined and pursued in conformity with the above mission and also with their new slogan: "Excellence in science and innovation". They have won new projects in basic research, their cumulated impact factor has surpassed by far that of the previous years, and they organised 5 international conferences. They have been included with six of their products into the list of the 100 most important Hungarian innovations. In order to strengthen further their innovation activity they have established together with the Fraunhofer Gesellschaft a joint venture company geared to innovation, with its registered site in Hungary. They play a leading role in the Industry 4.0 National Technology Platform Association and are founding members of both the 5G Coalition and the Artificial Intelligence Coalition. To enable a better liaising with the Hungarian industry partners they maintain sites in Győr and Kecskemét.

II. Outstanding results of 2018 in research, development and public relations

a) Research, development and innovation

In the following, besides of presenting the Institute's four key directions in basic research (computer science, systems and control theory, engineering and business intelligence, machine perception and interaction), five additional sub-sections summarise the application oriented achievements in the areas of vehicle and transport industry; production informatics and logistics; energy, sustainable development and precision agriculture; security, surveillance and medical applications; networks, distributed computing and the internet of the future.

THE MAIN DIRECTIONS IN BASIC RESEARCH

Computer Science

The main focus of their research in computer science lies in exploring the mathematical foundations of artificial intelligence and machine learning. They directly demonstrate the

practical applicability of their results in the areas of autonomous vehicles, smart factories, social sciences, human behaviour, anthropology, agriculture and biology. A characteristic feature of their approach is a strong collaboration of engineers and mathematicians: while their results are always experimentally validated over real data, but, due to the huge size of the problems, their algorithms have to be based on rigorously proven foundations, as well as on a deep knowledge in the theory of algorithms, probability and algebra.

Main results achieved in 2018:

- One of their main lines of research in the field of *parameterized algorithms* is the so-called "square root phenomenon" on planar graphs: it has been observed that for most parameterized problems on planar graphs, the optimal running time is exponential in the square root of the parameter.. They showed that the Traveling Salesperson Problem on directed planar graphs exhibits such behaviour; this result was known before only for undirected planar graphs. Furthermore, they have proved the surprising theorem that the Steiner tree problem does not have this property: there is no algorithm that is sub-exponential in the parameter. The significance of the result is that it is the first genuinely planar natural algorithmic problem where the square root phenomenon does not apply.
- In earlier research, tight lower bounds were given how the best possible running time can depend on *the tree width of the input graph*. Continuing this line of research, exact results were given for the general problem class of reflexive list homomorphism. For every fixed target graph, tight upper and lower bounds were given for the dependence of the running time on the tree width.
- They have contributed essentially to the recent breakthrough in the *determination of invariants of matrix tuples*. The problem and the result have impact even beyond the invariant theory, from the permanent-determinant problem of the theory of computation through the theory of division rings, up to the Brascamp-Lieb inequalities. Their main result is a deterministic polynomial time algorithm which solves a constructive variant of the problem. They gave an invited lecture about these developments at the Institute for Advanced Study in Princeton.
- They applied methods from the *theory of algebras with involution* to solve certain computational problems. One such problem is the simultaneous isometry of a collection of quadratic forms. For this algorithmic problem they gave a randomized polynomial time method over finite fields. The result can be applied to compute the isomorphism of certain groups, and also to attack a known authentication scheme. An efficient algorithm was found to transform collections of symmetric or skew symmetric matrices into each other via left or right multiplications. This task can be considered as a special case of the famous polynomial identity testing problem, too.
- They designed a *machine learning method* to find a linear function based on a sample of vectors whose distribution depends only on the values of the function over these vectors. The complexity of the algorithm is simply exponential in the number of values taken with nonzero probability, while polynomial in all other parameters for finite parameter sets. They have successfully applied their method as a building block of quantum algorithms for detecting structural symmetries in the data and, among others, extended the set of cases of the famous hidden subgroup problem that is solvable in polynomial time.
- They designed new multi-target approximation schemes for *the resource constrained shortest path problem*. They have proved that an approximation scheme exists only if the number of resources is constant. Furthermore, they have extended this theorem to other multi-target combinatorial optimization problems as well.

- They have shown that no ranking methods based on paired comparisons can satisfy two basic requirements – i.e. independence of irrelevant matches and self-consistency – at the same time. They have provided an axiomatic characterization of an index measuring the inconsistency of pairwise comparison matrices, together with an axiomatic characterization of the logarithmic least squares ranking method.

These research activities were funded largely by high-prestige grants: the *ERC Consolidator Grant* and the *MTA Momentum Grant*. Their main industrial partners in the research and development activities are: Ericsson Hungary, OTP Bank and Bosch.

Systems and control theory

Here they address systems modelling and identification, model reduction and identification, as well as the control of adaptive and robust distributed and networked systems.

- New results have been obtained in the field of model reduction, *signal processing and system identification research*. Based on the results of the Kolmogorov n -width theory, important parameters (fault limits) have been given for both H_2 and H -infinity cases related to the hyperbolic distance of the uncertain poles. A model reduction strategy was introduced that depends only on this information. Using a model reduction based on modal decomposition, that can preserve the consistency of the various states, high dimensional LPV (Linear Parameter Varying) and qLPV (quasi Linear Parameter Varying) systems describing the dynamic behaviour of flexible airplanes and similar engineering objects have led to new results.
- In the traditional, local approach to *control design based on geometric principles, the concept of parameter varying invariant subspaces* was introduced and, in the case of affine parameter dependence, efficient algorithms to calculate them were developed. In their recent research emphasis was placed on the analysis of lateral dynamics and driving stability of road vehicles by coordinating the steering system and the brake/drive systems.
- Research has been carried out *to explore the possibility of global (input-output) applications of geometric system theoretic methods*, revealing the common geometric background of robust control design methods. The geometric approach of Klein's theory has been used successfully in the world of robust control, e.g. where points in the geometrical meaning can be identified with stabilizable systems, while Möbius transformations provide movements that define the geometry. It has been shown that transformations of certain hyperbolic spaces provide a common background for robust control tasks and they have revealed the system theoretical properties of an action or group of actions invariantly describing a given property on the stabilizing set or on the set of all stabilizing controllers associated with the given performance level. A novel alternative geometry based parameterization was presented with a group theory approach that, unlike the Youla parameterization, is independent of coordinates, i.e. it requires the knowledge of the system and one stabilizing regulator only.
- In the fields of *fault detection and null space based structural reconfiguration* it has been shown how reconfiguring control design methods can be applied to guarantee the performance specification of the systems. Design methods were also developed to define dynamical filters generating the null spaces of LPV systems.
- In the field of *robust control*, design methods for structured uncertainties were elaborated jointly with researchers of the University of Minnesota. These methods are able to take into consideration the structure of the uncertainty in addition to the user defined structure of the controller. Thus, the tuning of the control structures applied in engineering (automotive industry, aerospace industry, etc.) becomes possible not only

for nominal but also for uncertain systems according to the H-infinity performance metrics.

- New results related to the *control theory of nonlinear systems* that were achieved on problems associated with robust control design using LPV and qLPV models have shown that Mobius transformations defined by unimodular matrices preserve the internal stability of the closed loop. They have also formulated an explicit formula for the calculation of the elements of the transformed loop.

The results obtained and described above have been primarily used in the energy, transport and vehicle industries. Together with industrial partners such as Airbus, Bosch and Knorr-Bremse they conducted activities in European and Hungarian collaborative research projects with the aim at exploiting the theoretical results directly in the industrial practice.

Engineering and business intelligence

Research in this field focused on the design, planning and control of cyber-physical production and logistic systems, as well as the adaptation of their operation to the ever changing conditions. By its nature, necessarily, interdisciplinary research was conducted in a number of fields related to computational theory, operations research, manufacturing science, production engineering and artificial intelligence. Main results obtained in 2018 are as follows:

- They participated in laying down the foundation of Fraunhofer's new strategic initiative aiming at the *biological transformation of manufacturing*. Recommendations were formulated on how to use and integrate systematically the biological and bio-inspired principles, materials, functions, structures and resources for the benefit of intelligent and sustainable manufacturing technologies and systems from the product design up to attaining the full potential of the production systems.
- They participated in an international study which has led to the conclusion that *production permeated by digitization* must become more effective in response to human needs in social, economic, and environmental terms. There is a need for increasing the social innovation of companies, for a more active inclusion of customers into the value chain, and for supporting this value co-creation process by cross-industrial IT platforms.
- *Constraint based mixed-initiative decision support workflow and system* for assembly process planning were defined and implemented. The workflow follows a hierarchical, iterative structure, departing from geometric models and terminating at the human-readable work instructions, which also covers the automatic generation of textual and animated 3D content.
- A new correlation based, randomized method was proposed which, under minimal statistical assumptions, can construct *non-asymptotic, distribution-free confidence regions* for stochastic dynamical systems estimated from empirical data.
- An input design approach was suggested for *resampling-type confidence region construction methods*, such as the *Sign-Perturbed Sums (SPS)* algorithm. The method selects inputs in such a way that minimizes the expected volume of the constructed (non-asymptotic, distribution-free) confidence region, provided that the inputs of the system can be chosen within given constraints.
- They have proved that the *single-machine scheduling problem with unit-time jobs, chain precedence constraints and a total weighted completion times' target function* is NP-hard.
- For the *online pickup and delivery problem with time window uncertainty*, where the pickup and delivery locations are known in advance, but the time windows are only defined by some distribution, they devised a new heuristic procedure which gives significantly better results in much shorter time than the previous methods.

- For the *conflict-free control of autonomously guided vehicles*, they devised a new, scheduling based approach which guarantees that all vehicles reach their destination, and even idle, blocking vehicles are moved out of the way.

Most of the targeted basic research was carried out in the frameworks of strategic national research projects (OTKA, GINOP, NKFIA). The theoretical results provided ground for follow-up industry-motivated applied R&D projects. Their experimental research environments – both the Smart Factory pilot environment at the Budapest site and the Industry 4.0 pilot production and logistics laboratory at SZTAKI's Győr site – have been substantially extended. These facilities support applied research and are open to education as well as to industrial innovation.

Machine perception and interaction

- *Orientation of robots based on visual information*: A deep convolutional neural network architecture has been developed which can be used to estimate the depth of each frame based on a single image view more precisely than with any other algorithms in the literature. Retaining the network architecture, with little further training, the procedure can be applied to both indoor and outdoor environments. Based on this deep learning structure, the semantic class of frames can also be well estimated.
- A solution has been provided for recognizing and tracking vehicles based on partial information (little data, partial shape) from *3D laser scanning* by introducing new 3D and 2D image features using deep learning convolutional nets that can detect road objects reliably even from a long distance.
- *Voxel model based 3D deep learning network* has been proposed for automatic semantic segmentation of point clouds generated by mobile laser scanning (MLS) that allows phantom regions and moving objects to be removed from raw MLS measurements, marking as static – so they can also be used as a landmark – the regions of street shapes.
- For estimating *epipolar geometry*, a method of calculating the relative displacement of cameras from five-point correlations has been proposed, instead of the former seven-point correlations, thus significantly reducing the runtime of robust estimation procedures. In cases where the affinity equations of the optical system are known in part, an effective method has been developed in which they can calculate relative displacement of the cameras from two known epipolar geometries for known internal calibration.
- A new method for *automatic registration of three-dimensional spatial measurements* with different characteristics and for assembling point clouds of moving vehicles without using sensors (GPS, IMU) has been provided. A Markov Random Field model has been proposed for recognizing moving shapes and variations on aggregated data using a representation of the depth map of point clouds.
- *Holographic measurement* provides the opportunity to restore not only the distribution of the intensity of objects, but also their phase distribution as well, which carries information of the shape and refractive index. This can be done relatively easily when using an off-axis system, but then the measurement is very sensitive to vibrations and the resolution of the sensor cannot be utilized on the whole surface. In the case of an in-line arrangement, however, although it allows a robust measurement, the phase restoration can only be carried out with a very slow iterative procedure, or the resolution of the reconstruction will not be large enough. They have provided a measuring arrangement and a numerical algorithm that combine these two types of holographic measurement methods, thus significantly increasing the speed of the reconstruction.
- *Phase contrast microscopy measurements* for transparent samples were extended and even replaced by numerical quantitative phase reconstruction methods using

holographic and intensity transport algorithms.

RESEARCH AND DEVELOPMENT ACTIVITY

Vehicle and transportation systems

Technology developments related to vehicle industry and transport were structured typically by the aerial and road transportation means and systems.

- In the field of *decision making strategies for autonomous vehicle systems*, research has focused on optimal handling of vehicle interactions. For risk assessment of overtaking manoeuvres, a probabilistic analysis, based on statistical samples and frequency functions, was given, and route-based optimal route search algorithms were used for route planning. Methods for calculating energy and time optimal solutions that involve neural networks to accelerate computational time have been discovered to handle intersection crossing interactions of autonomous vehicles.
- It was proved by research that coordination of the infrastructural elements of autonomous vehicles and intelligent transport systems has a significant impact on the *optimization of traffic characteristics*. Exploiting the benefits of coordinating microscopic and macroscopic transport elements is a theoretical and practical challenge. The Model Predictive Control (MPC) strategy was developed to harmonize the speed profile of autonomous vehicles and the magnitude of the traffic flow at the controlled entry points of the transportation network.
- An actuator-integrated, robust, LPV based reconfiguration strategy on the basis of set theory was developed in the research field of the *control theory problems of the variable- geometry suspension system*. Considering the compactness of the construction, variable-geometry systems may get a function in the controllability of the lightweight electric vehicles in future urban traffic.
- Significant amount of data can be obtained through the *communication and sensor networks of autonomous vehicles*. From the analysis of large-sized datasets, the availability sets of the intelligent actuators of the vehicle were defined by machine learning based methods, and a method was proposed for the estimation of the side-slip angle that is critical for the stability of the vehicle. The application of big data in the control design of autonomous vehicles represent a new, innovative method even in the international research arena.
- Research on camera based aerial image processing and reactive avoidance systems for *unmanned aerial vehicles (UAVs)* has been carried providing "sense and avoid" functions. The aircraft detects the intruder target machine on a visual basis with the on-board multi-camera vision system, the GPU imaging unit and the navigation equipment. By combining the fields of flight dynamics, optical sensing and deep learning, a new closed-loop control system that significantly increased the reliability of collision detection has been demonstrated. The technology elaborated provides a solution for the safe spatial separation of autonomous planes for UTM (unmanned traffic management) and contributes to the safety of following the GPS-controlled route.
- Using visual information, new results have been achieved in the research of *automatic landing systems*, relying on advanced data processing, image acquisition and sensor fusion methods. In addition to detecting the landing site with a given geometry, image processing and sensor fusion methods have been developed to monitor the confidence level of the estimation, required for safety critical applications. Reconfigurable control methods for automatic UAV landing algorithms were validated, taking into account the dropout of various sensors (ILS, GPS) in a Monte-Carlo simulation campaign.

- A *collision avoidance system based on deep learning* has been developed which is able to provide relative location information in case of known ground objects. The system was implemented on-board in an Unmanned Aerial Vehicles.
- The *flutter phenomenon resulting from wing flexibility* has been studied by investigating the multidisciplinary aerodynamics, the structural and flight dynamics of aircraft behaviour using efficient measurement and control techniques. These studies, including effective mathematical modelling, model reduction, measurement and control methods have raised significant international attention. Several models of different abstraction levels have been developed that cover the needs of the applications, from the flexible behaviour of the simple two degree-of-freedom wing, up to the dynamic behaviour of the entire aircraft. The real-time implementation aspects of the advanced control techniques have been solved by a custom-made avionics system providing high computational throughput and low latency.

Production informatics and logistics

Research, development and innovation in *production informatics and logistics* focused on the configuration, modelling and operation of production, service providing and logistic systems with some detours to the energy sector. Key results achieved in 2018 are as follows:

- A *cloud based, orchestrated IT platform for cyber-physical systems* has been created that is independent from cloud infrastructure providers. The system is capable of collecting and processing large amounts of data from production lines, as well as of performing simulations which capture the behaviour of the overall production system.
- They integrated *discrete-event and agent-based simulation methods*, capable of modelling production and/or logistic systems, for supporting operation planning, short-term performance prediction and evaluation of interaction modes in the same physical production environment. The agent-based model runs as a *digital twin* in parallel with the physical environment and, in case of a failure it takes over the control of the environment based on a distributed fault-tolerant logic and the predictions of the discrete-event model.
- A network theory based approach was elaborated for the robustness analysis of production networks consisting of numerous elements, with *special emphasis on the relationship of the complexity, robustness and efficiency aspects of the networks*.
- They elaborated a *machine learning based decision support method* that is capable of near real-time processing of structured or semi-structured data, obtained from manufacturing execution (MES) or supervisory and control data acquisition (SCADA) systems. The data gathered enable the periodic refinement of the prediction (typically regression based) models.
- The so-called *fluid computing concept* was adapted to cyber-physical production systems, with the primary aim to transform traditional manufacturing resources into networked, embedded components compatible with the Industry 4.0 distributed production paradigm.
- In cooperation with *Hitachi*, a method based on mixed-integer linear programming and advanced search heuristics has been developed for the joint optimization of the product design and assembly processes, as well as for the application of the results at the strategic level in production and capacity planning. The method was published after international patenting.
- They developed a new method, supporting the cost efficient *capacity management of robotized, modular assembly cells* applied in the automotive industry, considering both strategic and tactical level decisions.
- A control framework that integrates novel communication modalities was developed to

support *human-robot collaboration* based assembly. The application of contactless modalities, such as using VR-glasses, point cloud based gesture recognition or voice control, provides the required efficient communication for human-robot collaboration.

- Significant *machining efficiency increase* has been realized in industrial collaboration, under real production conditions, in the field of Electrical Discharge Machining (EDM) with the combined application of artificial neural network models, non-linear experimental design and iterative optimisation techniques.
- The Industry 4.0 pilot production and logistics system in Győr has been expanded with a new process execution architecture by making use of the so-called OPC Unified Architecture (OPC UA) modelling methodology. Within the European Learning Factories initiative, special emphasis was put on linking this facility to other similar ones at different locations, thus forming a distributed production network. A significant result was the parallel development of a collaborative human-robot assembly station at multiple locations that enables the transfer of interoperable algorithms and specific process solutions to workstations at other locations, leveraging the concept of the digital twin.

Energy and sustainable development

- Their industrial activity based on the long-term strategic cooperation with the MVM Paks Nuclear Power Plant Ltd. continued in the field of *control and supervision of power generation systems*. They played a key role in developing a high-level architectural concept for the control systems to be modernized and in defining the qualification requirements of the measurement circuits to be replaced as well as in the design of computer security of the turbine control system and the renewal of the testing environment for the Reactor Protection System (RPS).
- A *multi-target optimization approach* was applied for planning the heat supply in the residential sectors in Budapest. The possibility of nuclear energy co-generation development in the region of Paks was formulized and investigated in the form of a special distribution problem.
- The *quality control of the renewable pellet heating materials* was reviewed. New raw material measurement methods were integrated into the production process, and recommendations were made for the extension of the related ISO standard.

Security, surveillance, medical and biological applications

- *Remote sensing methods for environmental and safety applications*: A new algorithm and methodology for mapping and monitoring small-scale wetlands by fusing different segmentation techniques based on satellite multispectral images has been completed.
- A *holographic method* has been developed that replaces the linear search process of microscope focus detection. It makes possible to calculate the focus explicitly from a single remote measurement, making it easier to identify the location of the objects, improve visualization, and significantly increase measurement speed. The results were used in the state-of-the-art automated urine analysers developed and manufactured in Hungary.
- In the *cyber security* domain they developed a decentralized solution where contributing parties in federated learning can be held accountable for, and have their own model updates audited, without resorting to a centralized training set. Experiments have shown that the increased complexity caused by the so-called blockchain technology has a limited performance impact on the federated learning, while providing full transparency over the distributed training process of the neural network.
- HunCERT is continuously providing *cyber security incident response* to Hungarian Internet Service Providers. In the course of 2018, it has processed more than 6000

incident reports, issued 9 urgent security alerts, organised a security workshop and maintained its *national computer security sensor network*. This activity is carried out in close cooperation with National Cyber Security Centre (GovCERT) which is also using solutions produced by the Institute.

- Commissioned by the Governmental Information Development Agency, the Institute is operating EduID federative authentication infrastructure, providing access to several thousands of online services for more than 100 national research and higher education bodies, partaking in projects such as the digital reconstruction of the Széchenyi National Library. They are key contributors to the GÉANT GN4 EduTeams programme, aiming at the establishment and further development of the federative identity management services for the European education and research network.
- A *vision based medical examination device* has been developed that can detect the most important physiological signals (pulse, breathing) of humans and animals remotely on a non-contact way. Hospital testing of the system has been started.
- As one of their first applications of artificial intelligence to bioinformatics, in collaboration with the Semmelweis University they investigated the phenomenon of *protein translocation*. Certain proteins frequently change location within the cell to fulfil certain roles, while others rarely or never change location. So far, little was known about these proteins, despite the fact that translocation has a key role both in cell functioning and generating diseases as well. By using gradient boosting, they were able to predict the translocation affinity of 13066 proteins.
- In another application, together with researchers from the Genetics Department of Eötvös University, they used artificial intelligence to *predict the role of proteins in the ageing process*. In their result, they have combined the predictions of several mathematical models to rank human proteins by their anticipated importance in the ageing process.

Networks, network systems and services, the future of the Internet

- They considered the *failures of wide area communication networks* due to natural disasters or malicious attacks with geographically extensive impact. They developed an efficiently computable stochastic model for studying certain regional failures. Their basic assumption was that such disasters make the links and nodes of a larger geographic area fail simultaneously (correlated failures occur). The model/method has been validated by computational experiments.
- They described a new neural embedding scheme for *dynamic networks in which the edges arrive in a data stream*. Their algorithm can maintain the similarity and the importance of network nodes by updating the representation on-the-fly, as the new edges arrive. Based on invariant random fields, they gave a new non-personalized, item-to-item recommender method that can handle rare items as well.
- In cooperation with the Wigner Data Center they continued the continuous extension of the *MTA Cloud* and the provision of support to their users. The major goal of further development was to expand the capabilities of MTA Cloud towards artificial intelligence. Therefore, concerning the hardware solution, the cloud was mainly extended with GPGPU cards and in the software, they have been investigating the tools and environments that support machine learning and big data applications like TensorFlow, Keras, DL4J, Spark. As a result of the research they have created a multi-machine high performance Spark cluster by which large scale MI and big data applications can be executed in an efficient way. On the web page of Occopus the required infrastructure descriptors of the Spark cluster can be accessed. By means of these descriptors scalable, cloud-agnostic Spark clusters can automatically be built in

the major cloud types including the OpenStack of MTA Cloud as well.

- In the framework of the H2020 project COLA they have been pursuing research in two main directions. One of the major goals was the development of the Policy Keeper component whose task is the automatic scaling of the MiCADO based applications in clouds in such a way that the parameters controlling the scalability options could be collected and used in the most flexible way. The other goal was to optimize the decision making mechanism in Policy Keeper by applying reinforcement learning methods.
- In the H2020 project CloudiFacturing, they have developed for Industry 4.0 a data transfer technology that enables data transfer among various types of storages (e.g. HPC, Cloud and local solutions). The method developed facilitates uniform and efficient data transfer among the selected storages and supports the execution of large scale simulations and complex analytics related to mechanical engineering processes.
- They played a key role in the development, implementation and launch of the new version of the national scientific publication registry system called Hungarian Scientific Bibliography (MTMT2). The software development of the final version of the entire system has been completed, its final testing has been performed that checked from the aspect of live operation each and every vital software feature. The complete database managed by the MTMT1 system has been migrated, in the course of which automatic data cleaning has also been carried out.
- A new and innovative open source virtual and extended reality programming library has been created under the name ApertusVR. The ApertusVR software development toolkit has defined a unique abstraction layer that addresses the problems of virtual reality industry application development.

b) Science and society

The communication policy and PR activity of the Institute are determined by the usage of advanced channels, interactivity, transparency, corporate social responsibility and the dynamic mixing of the researchers' attitude with the marketing approaches. In 2018 the Institute surpassed the previous years by issuing 15 press releases, 140 reports on institutional news and events as well as having nearly 220 media appearances.

Besides the online media, their relationships with the television, radio and the printed media were further reinforced. Their activities were presented in 2018 by a series of articles in *Forbes Magyarország, Index, Népszabadság, MTI, HVG, Origo, 24.hu, Magyar Nemzet, hirado.h, Innotéka, and 444.hu*. Many of their scientific results were published in the regional media – like boon.hu, eszak.hu, delmagyar.hu – the biggest professional online and printed media and the partners' newsfeeds, e.g. in *qubit, Autopro, Computerworld, GyártásTrend, Techstory, Techmonitor, Járműipar, Piac és Profit and IT Business*. The Institute's experts gave interviews at several occasions in the most important commercial and national media like *Kossuth Rádió, Petőfi Rádió, Info Rádió, M5 TV, M1 TV, ATV and Hír TV*.

The contents presented in the social media was updated on a daily basis and their *Facebook* page has nearly 900 followers; the approximately 400 entries of the year generated 45.000 downloads and the number of organic accesses increases exponentially. Their official *LinkedIn* site published 180 entries in 2018, some 1000 people follow the Institute on this business social media. Besides the above, they are represented by 4 individual pages on *Wikipedia*, and some 40 videos were uploaded on their official *YouTube* channel with the highest number of views being around 5500 annually. A new concept for the online Newsletters has been elaborated to strengthen both the internal and external partner communication. 75 newsletters have been issued so far.

The Institute continued in 2018 its traditional initiative of the “Researchers’ Night” event. They received their visitors, altogether 400 people, besides their premises in Budapest and Győr, in Burgas, too. They were present at the “*Feast of the Hungarian Science*” event by delivering an opening presentation. Similarly to the past years, they took part with their smart phone applications on the “*Digital Thematic Week*”, the “*Fall Festival of the Hungarian Museums*”, the “*World Day of Tourism*” and the “*Day of Hungarian Poetry*”. Their portfolio of free downloadable touristic applications was extended to cover the *Open Air Folk Art Museum at Szentendre*, the built heritage of *Inner Ferencváros* and the *Educational Path of Ipolytarnóc*.

In cooperation with Bosch Rexroth which is responsible within the Bosch Group for the Industry 4.0 technological developments and implementation, they organised the workshop “*The Digital Factory of the Future*” featuring international lecturers as well, and, for the second time, the event “*INDIGO Industrial Digitization Professional Day*” was held with demonstrations on today’s relevant topics, the international trends and the professional services of EPIC InnoLabs Ltd. Both meetings were attended by 150-200 participants representing all segments of the Hungarian I4.0 ecosystem: large companies, SMEs, ICT service providers, professional organisations and governmental decision makers were present. The Institute appeared also on the “*Days of Industry*” spring fair organised by Hungexpo and other regional events, too, presenting its most recent achievements in robotics.

In 2018 six products of the Institute were listed in the publication “*The Top 100 most interesting Hungarian innovations*”. They contributed to selecting the winner of the “*Factory of the Year*” competition in the Industry 4.0 category, and they were nominated for the *Innovation Radar Prize 2018*.

Several internal events significant from the science and society relationship point of view were held: for instance the commemorative meeting honouring the first competition in informatics for grammar school students, then the launching of the *Rudolf E. Kalman Distinguished Lecturer Programme* and initiating the series “*SZTAKI meetups*”. Students of elementary and grammar school classes could visit their temporary exhibition displaying old IT devices, classical computers and other valuable relics.

The Institute, in cooperation with the Wigner Data Center continuously supports and develops the *MTA Cloud* research cloud infrastructure that is servicing the high computation needs of the MTA research institutes. Also, they developed the new digital archiving software system of the Hungarian Scientific Bibliography (MTMT2) and perform the maintenance thereof.

III. Domestic and international relations in 2018

In 2018 they played a decisive role in the establishment, then the definition of the operational environment and processes of EPIC InnoLabs Ltd, a joint venture company of MTA SZTAKI and the Fraunhofer Gesellschaft. The profile of the new innovation oriented organisation covers currently Industry 4.0 consultancy and training, optimization of production and logistic processes, production scheduling, industrial data analysis, artificial intelligence, integrated robots and sensors, and is being continuously expanded to bring the R&D achievements and competencies of the entire Institute close to its industrial partners.

Organization of international and important national events

They successfully completed the first phase of the project “Centre of Excellence in Production Informatics and Control” (EPIC), the most important outcome of which was the establishment of *EPIC InnoLabs Non-profit Ltd.* as a joint venture with the German *Fraunhofer Gesellschaft*.

With respect to this project, too, the most prominent event was the “*German-Hungarian Innovation Day*” held in Budapest on 25th May that was co-organised with the Fraunhofer Gesellschaft. At the meeting, distinguished personalities like the Chairman of the Fraunhofer Gesellschaft, the Chairman of MTA, the Minister of the Ministry of Innovation and Technology, the Chairman of FKFIH and the Director of SZTAKI have outlined their views on research, development and innovation to an international audience.

In co-organization with Hungarian universities the following highly reputed conferences were held in Budapest in 2018:

- 9th Hungarian Conference on Computer Graphics and Geometry, 21-22, March;
- 20th European Conference on Mathematics for Industry (ECMI 2018), 18-22, June;
- 25th Annual Conference of the European Operations Management Association (EurOMA 2018), 24-26, June;
- 8th CIRP Conference on High Performance Cutting (HPC 2018), 25-27, June;
- 16th International Workshop on Cellular Nanoscale Networks and their Applications (CNNA 2018), 28-30, August;
- 22nd European Conference on Advances in Databases and Information Systems (ADBIS 2018), 2-5, September.

International relations

Members of the Institute play an active role in the leadership of the most significant international societies relevant to their research domain (including *IEEE*, *CIRP*, *IFAC*, *IMEKO*, *IAPR*), as well as in the working committees thereof.

The Institute’s successful participation in the *EU research programmes* continued in 2018: within the Horizon 2020 programme, up to now 16 winning projects may be reported with SZTAKI having the consortium leadership in 4 of them.

The Institute has a strong practical project background in research and technological development for *commercial aviation and vehicle industry*. With respect to the research in avionics, the relationships with the Department of Aerospace Engineering and Mechanics at the University of Minnesota, the US Office of Naval Research (ONR), the Laboratoire de l’Intégration du Matériau au Système at the University of Bordeaux, as well as the German Aerospace Centre (DLR) and the European Space Agency (ESA) should be mentioned.

As a winner of the high-prestige *Teaming* research excellence programme of the EU *Horizon 2020 Widening* programme, the project “*Centre of Excellence in Production Informatics and Control*” (EPIC) was launched in 2017. In 2018 the institutionalised foundation has been created to operate an internationally recognised Centre of Excellence of the cyber-physical systems in the long-term European cooperation of SZTAKI, the Fraunhofer Gesellschaft Germany and two faculties of the Budapest University of Technology and Economics: those of Mechanical Engineering and of Transportation and Vehicle Engineering.

The Institute runs the *Hungarian Office of World Wide Web Consortium (W3C)* that participates in the activities of the Working Groups, thus directly contributing to the development of the Web and having early access to information about new technical features and tendencies. The W3C Hungarian Office promotes the adoption of W3C recommendations in Hungary, provides information on W3C technologies and brings people interested in web technologies and international experts together.

Research and development cooperation with the industry

At the Institute it is considered as a task of utmost priority that the results of their economic and social research related to industrial digitization as well as the Industry 4.0 ecosystem

oriented concept be broadly publicised and utilised.

In Dec. 2017, the Industry 4.0 National Technology Platform (Ipar 4.0 NTP) established in May 2016 under their leadership and comprising the parties interested in the digital transformation of industry, like research institutes, educational institutions, professional bodies and industrial companies with premises in Hungary, was transformed into a legal entity of an association. In 2018 they played a key role in the operation of the Platform, and acted as its representative both in Hungary and abroad. They also catalysed a nationwide survey on the Industry 4.0 readiness of industrial companies, performed the evaluation of the responses and published a report on it.

From middle 2018 on, the cooperation with the SMEs has more and more become the responsibility of InnoLabs Ltd. that serves also – in the framework of a strategic collaboration – as an outstanding local competence centre for *Siemens'* PLM software lines *Tecnomatix* and *Preactor APS* in the field of discrete-event driven simulation as well as in production planning and scheduling. A couple of companies from the automotive sector addressed InnoLabs with their problems in robotics. The professional background to meet these demands is provided by the Institute. They pursue joint research and development activity with several Hungarian companies (e.g. with AQ Anton in scheduling and process optimization, with Aventics in scheduling and paperless production). A new research project was launched together with the Fraunhofer Gesellschaft in the topic of the biological transformation of the production

The joint research work dating back to more than 10 years with Hitachi Ltd., Manufacturing Technology Research Center has been pursued. This year, earlier international joint patents with Hitachi have been renewed.

The Institute is contributing with the results of its discovery research in the vehicle industry to the eminent scientific activity being pursued in Győr, thus supporting there the regional scientific and technological R&D&I activities. The basis of this cooperation is the *Centre of Excellence in Research of Vehicle Technologies (J3K)*, founded by the Hungarian Academy of Sciences on the premises of the Széchenyi István University. The operation of the Centre is supported by MTA, Audi Hungaria, the Széchenyi University and the city council of Győr.

Their scientists took part in the planning and specification works of the new *automotive proving ground to be built in Zalaegerszeg, Hungary*. The proving ground supports the mandatory functional and performance testing of the prototypes of self-driving vehicle technologies in the pre-production phase. The experts of the Institute contributed to the legislative and regulatory actions to support authorities with an applicable legal framework for the control and regulation of licencing self-driving vehicles on public roads.

In the area of energetics, the work concerning the safe lifetime extension of nuclear reactors, the continued collaboration with the Paks Nuclear Power Plant, Hungary is to be mentioned. The capacity reservation efforts were made in close cooperation with MVM Paks II Power Plant Development Company, together with MVM ERBE ENERGETIKA Mérnökiroda Zrt.

The Institute operates affiliate sites in the cities of Győr and Kecskemét.

National relations, participation in higher education

The Industry 4.0 National Platform Association has been established under the leadership of the Institute which is a founding member of both the Hungarian 5G and the AI Coalition.

The Institute continues to view teaching activities in graduate and post-graduate education as an important ingredient of its research work and also as an indispensable part of building the future. Hence, many researchers at the Institute also fulfil teaching mandates at various Hungarian institutions of higher-level education, including BME, ELTE, Corvinus, Pannon

University, SZE, PTE, ME, PPKE and Kecskemét University. On average, around 20 PhD students conduct research work at the Institute under the tutorship of researchers. 25 researchers at the Institute act as external and 5 as internal founding members in various doctorate schools.

IV. Summary of the most relevant national and international grants won in 2018

Artificial Intelligence Exploring the Mathematical Foundations of Artificial Intelligence
(*Benczúr András, NIH/NFÜ/NKFIH 2018-1.2.1-NKP, 274 538 326 Ft, 2018-2021*)

The goal of the project is to explore the mathematical theory of artificial intelligence and the practice of machine learning. Additionally, pilot interdisciplinary projects will be realised that may directly demonstrate the practical applicability of the theoretical research.

eIDAS eIDAS identification during KYC procedures at financial institutions
(*Benczúr András, EIT Digital Grant 2018, 40 000 €, 2018-2018*)

The goal of the project is to create the IOX online identity checking platform in order to support the remote execution of the online handling of bank customers. The task is to compare the customer's ID photo with the video chat and thus to confirm his/her actual presence.

Industrial digitalization Research on prime exploitation of the potential provided
by the industrial digitalization
(*József Váncza, NKFIH ED_18-2-2018, 956 403 000 Ft, 2018-2023*)

The project aims at conducting discovery research of mathematical and AI methods as well as the application of the results in various areas like robotics, design and control of production and logistic systems, and management of the energy systems.

VLFT Virtual Learning Factory Toolkit
(*Péter Kovács, EU ERASMUS+, 41 700 €, 2018-2021*)

The project is about to develop the Virtual Learning Factory Toolkit (VLFT) and to integrate it into existing digital devices, making the results of digital R&D – like modelling, analysis and virtual/extended reality – accessible for students in engineering for training purposes.

StaProZell Production stability in reconfigurable cell oriented assembling lines
through digital twins
(*Dávid Gyulai, FFG- Produktion der Zukunft, 96 371 €, 2018-2021*)

The goal of the project is to develop new methods for production and capacity planning for modular assembling lines, using digital twin models.

MTA PDP Manifolds and deep structures
(*Bálint Daróczy, MTA PPD2018, 33 012 000 Ft, 2018-2021*)

Theoretical and experimental research is pursued in the most relevant areas of machine learning, with the aim of analysing the highly structured data of the cyber-physical systems. The methods are utilised in different areas, such as e.g. autonomous vehicles, social sciences, behaviour detection, and anthropology, agriculture and biology.

NKFIH TÉT-FR Integration of velocity and suspension control to enhance automated
driving comfort in road vehicles
(*Péter Gáspár, NKFIH TÉT-FR-2018, 1 981 000 Ft, 2019-2020*)

The subject of the project is the tuning of the characteristics of the adaptive semi-active suspension in coherence with longitudinal speed control, based on linear parameter varying (LPV) control design in order to ensure driving stability and to improve driving comfort.

NKFIH SNN Smart Optimization in Sustainable Supplier Chains

(*Tamás Kis*, NKFIH SNN_18, 35 754 000 Ft 2019-2021)

The subject of the project is to explore the design and scheduling problems in supplier chains, with special consideration to the constraints of reutilisation and energy minimization.

Lung cancer diagn. CT Image Analytic Lung Cancer Diagnostic Artificial Intelligence
(*András Benczúr*, GINOP 2.2.1, 352 014 600 Ft, 2019-2021)

The goal of the project is to determine – using machine learning methods – the optimal slice number in CT screening for the lung cancer diagnostics, in dependence of ray hygienic and detection sensibility factors.

V. List of the most significant scientific publications in 2018

Books

1. Gáspár, P.; Németh, B.: Predictive Cruise Control for Road Vehicles Using Road and Traffic Information, Springer Int. Publishing (2018), p. 236. ISBN: 9783030041151
2. Keveczky, L.; Bars, R.; Hetthéssy, J; Bányász, Cs.: Control Engineering, Springer Singapore (2018), p. 532. ISBN: 9789811082962
3. Keveczky, L.; Bars, R.; Hetthéssy, J; Bányász, Cs.: Control Engineering: MATLAB Exercises, Springer Singapore (2018), p. 275. ISBN: 9789811083204
4. Kornai, A. Szemantika, Typotex, budapest, (2018), p. 331. ISBN: 9789632799704
5. Kornai, A.: Formal Phonology, Routledge (2018), p. 231. ISBN: 9781138321144
6. Szederkényi, G.; Magyar, A.; Hangos, K.M.: Analysis and Control of Polynomial Dynamic Models with Biological Applications, Academic Pr. (2018), p. 184. ISBN: 9780128154953

Publications in professional periodicals

7. Benedek, Cs.; Gálai, B.; Nagy, B.; Jankó, Zs.: Lidar-based Gait Analysis and Activity Recognition in a 4D Surveillance System, IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS FOR VIDEO TECHNOLOGY, Vol. 28, No. 1, 2018, pp. 101-113.
8. Csató, L.: Characterization of an inconsistency ranking for pairwise comparison matrices, ANNALS OF OPERATIONS RESEARCH, Vol. 261, No. 1-2, 2018, pp. 155-165.
9. Györgyi, P.; Kis, T.: Minimizing the maximum lateness on a single machine with raw material constraints by branch-and-cut, COMPUTERS AND INDUSTRIAL ENGINEERING, Vol. 115, 2018, pp. 220-225.
10. Hajnal, A.; Kecskemeti, G.; Marosi, A.Cs.; Kovacs, J.; Kacsuk, P.; Lovas, R.: ENTICE VM Image Analysis and Optimised Fragmentation, JOURNAL OF GRID COMPUTING, Vol. 16, No. 2, 2018, pp. 247-263.
11. Ivanyos, G.; Kutas, P.; Rónyai, L.: Computing Explicit Isomorphisms with Full Matrix Algebras over $F_q(x)$, FOUNDATIONS OF COMPUTATIONAL MATHEMATICS, Vol. 18, No. 2, 2018, pp. 381-397.
12. Kardos, Cs.; Váncza, J.: Mixed-initiative assembly planning combining geometric reasoning and constrained optimization, CIRP ANNALS - MANUFACTURING TECHNOLOGY, Vol. 67, No. 1, 2018, pp. 463-466.
13. Kerepesi, Cs.; Daróczy, B.; Sturm, Á.; Vellai, T.; Benczúr, A.: Prediction and characterization of human ageing-related proteins by using machine learning, SCIENTIFIC REPORTS, Vol. 8, 2018, Paper No.: 4094, p. 13.
14. Kovács, A.: On the Computational Complexity of Tariff Optimization for Demand Response Management, IEEE TRANSACTIONS ON POWER SYSTEMS, Vol. 33, No. 3, 2018, pp. 3204-3206.
15. Lokshtanov, D.; Marx, D.; Saurabh, S.: Slightly Superexponential Parameterized Problems, SIAM JOURNAL ON COMPUTING, Vol. 47, No. 3, 2018, pp. 675-702.

16. Luspay, T.; Péni, T.; Gőzse, I.; Szabó, Z.; Vanek, B.: Model reduction for LPV systems based on approximate modal decomposition, *INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN ENGINEERING*, Vol. 113, No. 6, 2018, pp. 891-909.
17. Németh, B.; Gáspár, P.; Hegedűs, T.: Optimal Control of Overtaking Maneuver for Intelligent Vehicles, *JOURNAL OF ADVANCED TRANSPORTATION*, 2018, Article ID: 2195760, pp. 1-12.
18. Peni, T.; Vanek, B.; Liptak, Gy.; Szabo, Z.; Bokor, J.: Nullspace-Based Input Reconfiguration Architecture for Overactuated Aerial Vehicles, *IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY*, Vol. 26, No. 5, 2018, pp. 1826-1833.
19. Rózsa, Z.; Szirányi, T.: Obstacle Prediction for Automated Guided Vehicles Based on Point Clouds Measured by a Tilted LIDAR Sensor, *IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS*, Vol. 19, No. 8, 2018, pp. 2708-2720.
20. Rödönyi, G.: An Adaptive Spacing Policy Guaranteeing String Stability in Multi-Brand Ad Hoc Platoons, *IEEE TRANSACTIONS ON INTELLIGENT TRANSPORTATION SYSTEMS*, Vol. 19, No. 6, 2018, pp. 1902-1912.
21. Tsutsumi, D.; Gyulai, D.; Kovács, A.; Tipary, B.; Ueno, Y.; Nonaka, Y.; Monostori, L.: Towards joint optimization of product design, process planning and production planning in multi-product assembly, *CIRP ANNALS - MANUFACTURING TECHNOLOGY*, Vol. 67, No. 1, 2018, pp. 441-446.
22. Zarándy, A.; Horváth, A.; Szolgay, P.: CNN Technology-Tools and Applications, *IEEE CIRCUITS AND SYSTEMS MAGAZINE*, Vol. 18, No. 2, 2018, pp. 77-89.